PROTECTIVE PACKAGING COMPRISED OF SHAPE MEMORY FOAM

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional application Serial No. 60/418,928, filed October 16, 2002, and entitled "Protective Packaging Comprised Of Shape Memory Foam".

BACKGROUND OF THE INVENTION

1. Field of the Invention

One aspect of the present invention relates to protective packaging comprised of shape memory polymeric foam and methods of using shape memory polymeric foam in protective packaging applications.

2. Background Art

Protective packaging structures are often used to protect an article from physical shock during storage and transport. As an example, to protect valuable or fragile articles from physical shock or other external forces during shipping, storage, loading, or unloading, it is desirable to place articles that are being shipped in a box or a container. However, in order to provide adequate levels of protection, it is often necessary to place additional protective packaging structures between an article that is being shipped and the walls of an outside box or a container.

Polymeric foams are commonly utilized in packaging applications as protective packaging structures. These foams are usually inserted between an article that is being shipped and the walls of a container or a box. Foams most frequently utilized in protective packaging are polyurethane foams, however, polyolefin, polystyrene, and other polymeric foams are utilized as well. These polymeric foams are generally cellular, low-density materials. As a result, polymeric foams are

bulky materials that are therefore expensive to transport and store. Consequently, the main drawbacks of polymeric foams are high costs of storage and transportation from the manufacturers to the end-users of the polymeric foams.

As a result, large-volume users, otherwise referred to as customers, of polymeric foams used in protective packaging often purchase the reagents and produce polyurethane foams on-site. The reagents used in production of polyurethane foams are isocyanate compounds and polyol compounds, which are usually in the liquid form making them less bulky and therefore less costly to transport and store than the solid polyurethane foams.

Most common packaging applications involve wrapping of an article that is to be protected and shipped with a layer of protective material (such as a plastic sheet or a film) and placing it into a container or a box. Subsequently, isocyanate compounds and polyol compounds are co-injected into a container, where they react to form polyurethane foam. If done properly, polyurethane foam rises and fills the spaces between a wrapped article and the walls of a container, providing a custom-fit protective packaging. Alternatively, isocyanate compounds and polyols compounds can be co-injected into a bag. These bags have a vent that allows some CO_2 to escape. These bags (while the reagents are reacting and foaming) are simply placed in a container around an article being protected and shipped, and the container is closed. As the reagents react, the polyurethane foam in the bags rises, filling the voids in the container, creating a custom-fit protective packaging. *See* U.S. Pat. Nos. 4,800,708, 4,854,109, and 4,938,007.

The main drawback of customers synthesizing polyurethane foams is that handling of the reactive chemicals (reagents) can be extremely messy, and if not properly controlled, the foam characteristics can vary from the desired properties. For instance, inadequate foaming can result in compromised protective packaging properties. On the other hand, excess foaming can result in spillage. Furthermore, the foaming reagents (reactive chemicals) are very sensitive to atmospheric conditions. Therefore, special care is required in handling and storage of these reagents, which can require a significant capital investment for proper storage

containers for isocyanate compounds and polyol compounds. Furthermore, the end-users are required to purchase the systems for pumping and co-injection of the reactive reagents, which can be costly and difficult to maintain.

To circumvent these problems, manufacturers of protective packaging materials have developed a deployable foam-in-a-bag system that contains the reactive reagents. In these deployable foam-in-a-bag systems isocyanate compounds and polyols compounds are stored in separate pouches within a single bag. Prior to application, pouches are ruptured and the reagents mix and react in a bag to form foam. While the reagents are reacting to form a polyurethane foam, the bags are simply placed in a container around an article being shipped, and the container is closed. As the reagents in the bag react, the polyurethane foam in the bag rises, filling the voids in the container, and creating a custom-fit protective packaging. *See* U.S. Pat. Nos. 6,398,029, 4,854,109, 5,027,583, 5,139,151, 5,699,902, and 5,873,221.

However, these deployable foam-in-a-bag systems have several notable disadvantages. Most commonly the reactive reagents do not completely mix which can result in foams that are structurally inappropriate or in some cases no foam at all. Incomplete reaction also results in unreacted isocyanate compounds, which are environmentally undesirable and subject to regulations as such. On the other hand, fully reacted polyurethane foams are much more environmentally friendly. In addition, isocyanate residue can be hazardous to an article being packaged. Furthermore, the foaming reagents are very sensitive to atmospheric conditions. Therefore, special care is required in sealing of the pouches and bags. In addition, the foam-in-a-bag systems are limited in a variety of shapes and sizes that they can deploy to. Also, the foam-in-a-bag systems are difficult to produce in a large variety of shapes and sizes. For these reasons, in packaging applications, the deployable foam-in-a-bag reactive systems have had a limited success in replacing the polymeric foam materials made from more conventional methods.

Therefore, there is a need for polymeric foam materials that are inexpensive to transport and store, however, that provide adequate levels of

protection for protective packaging applications, and eliminate the need for customers to synthesize their own polymeric foams or use reactive deployable systems.

SUMMARY OF THE INVENTION

A first embodiment of the present invention is a protective packaging for protecting an at least one article. The protective packaging includes a shape memory foam (SMF) structure conforming to at least a portion of the at least one article for protecting the at least one article. The SMF has a glass transition temperature (T_g). The SMF structure can have a T_g of at or above about 21°C. The SMF structure can be rigid below the T_g and elastic above the T_g. The SMF structure can have a shape memory characteristic such that when the SMF structure in an original shape is deformed or compressed above the T_g to produce a compressed shape and cooled in the compressed shape below the T_g, the SMF structure retains the compressed shape without the need of external forces and when the temperature is raised above the T_g, the SMF structure returns substantially to the original shape.

According to the first embodiment, the SMF structure can be a thermoset or thermoplastic SMF. The SMF structure can be composed of a structure of polyurethane foam produced by reacting an isocycate and a polyol. The polyurethane foam can be prepared using a polyol selected from the group comprised of an aromatic polyester polyol, a polycarbonate polyol, a polyether polyol, and mixtures thereof. The polyol can have an average functionality between about 2 and about 4. Further, the isocyanate can be an aromatic isocyanate having a functionality between about 2 and about 3. The polyurethane foam can be produced by reacting the isocyanate with the polyol and a chain extender. Additionally, the SMF can have a substantially open cell structure. In certain applications of the first embodiment, the SMF is compressible to less than about 50% of the original volume. The SMF can further include a natural or synthetic additive. Further, the SMF structure can be at least partially wrapped, coated,

laminated, or encased in a film. The SMF can also be hydrophobic and/or resistant to moderate levels of ionizing or non-ionizing radiation.

According to a second embodiment of the present invention, a method for producing a protective packaging for protecting an at least one article is disclosed. The method includes placing a shape memory foam (SMF) structure having a glass transition temperature (T_g) and an at least one article in a container, whereby the SMF conforms to at least a portion of the at least one article to protect the at least one article. The SMF can be at a temperature of about below or about above the T_g.

The second embodiment can also include the following steps: deforming or compressing the SMF structure in an original shape to produce a compressed shape, cooling the compressed shape to below the T_g to retain the compressed shape, raising the temperature of the compressed shape to above about the T_g to substantially regain the original shape, whereby the original shape or the compressed shape conforms to at least a portion of the at least one article to protect the at least one article. The raising of the temperature of the SMF can be accomplished by a process selected from the group consisting of convection heating, conductive heating, microwave heating, or chemical reaction. The cooling of the SMF can be accomplished by a process selected from the group consisting of free convection, forced convection, refrigeration, conductive cooling, cooling baths, and liquid gas or nitrogen.

Additionally, the second embodiment can include the step of providing a plurality of SMF structures and a plurality of articles. In certain applications, the plurality of SMF structures are stackable for protecting the plurality of articles.

According to a third embodiment of the present invention, a method for producing a protective packaging is comprised. The method includes providing a shape memory foam (SMF) structure having a glass transition temperature (T_g), providing a transportation or storage container, deforming or compressing the SMF

structure to produce a compressed shape, and placing he compressed shape in the transportation or storage container. The compressed shape can be substantially flat. The method of the third embodiment can further include providing a plurality of SMF structures suitable for deforming or compressing into deformed shapes for storing in the transportation or storage container.

The above embodiments and other embodiments and features of the present invention are readily apparent from the following detailed description of the best mode for carrying out the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention which are believed to be novel are set forth with particularity in the pending claims. The present invention, together with the further objects and advantages thereof, may be best understood with reference to the following description, taking in connection with the accompanying drawings:

FIGURE 1 is a diagram illustrating a shape memory cycle of a shape memory foam used in accordance with an embodiment of the present invention;

FIGURE 2 is a photograph of a shape memory foam used in accordance with an embodiment of the present invention as a compressed sheet and in its original block shape;

FIGURE 3 is a schematic of the deployment of a shape memory foam used in accordance with an embodiment of the present invention from a compressed shape to its original shape that is induced by heating above the T_g;

FIGURE 4 describes an application in which an article (A) is packaged in between two pieces of protective packaging made of shape memory foams, which in elastic state, conform around an article and the walls of a container;

FIGURE 5 describes an application in which an article (A) is packaged in between several pieces of protective packaging made of shape memory foam, which in elastic state deform around an article and the walls of a container;

FIGURE 6 describes an application in which protective packaging made of shape memory foam is deployed from a compressed shape (shape II) to its original custom-made shape (shape I) at a temperature above the T_g;

FIGURE 7 describes an application in which protective packaging made of shape memory foam is deployed from a compressed shape to its original custom-made shape at a temperature above the T_g;

FIGURE 8 describes an application in which protective packaging made of shape memory foam is deployed from a compressed shape to its original custom-made shape at a temperature above the T_g;

FIGURE 9 shows how protective packaging made of shape memory foam can be used to protect and package two or more articles;

FIGURE 10 describes an application in which a sheet of protective packaging made of shape memory foam is applied (wrapped) around an article while the shape-memory foam is elastic (its temperature above the T_g); and

FIGURE 11 describes how protective packaging made of shape memory foam(s) can be deformed in a die (D) at a temperature above the T_g, and then cooled in a die to a temperature below the T_g to produce a shape that custom-fit and protective one or more articles (A).

DETAILED DESCRIPTION OF EMBODIMENTS OF THE PRESENT INVENTION

As required, the detailed embodiments of the present invention are disclosed herein. However, it is to be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms. Therefore, specific functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

The invention will be described in more detail with reference to the following examples, which are not intended to restrict the scope of the invention. The protective packagings of the present invention have a shape memory foam (SMF) as at least one of its components.

The shortcomings in protective packaging applications of conventional foams and the reactive systems that require customers to synthesize polyurethane foams can be eliminated by the protective packaging made of "shape memory foams," which above their glass transition temperature are elastic and can regain their original shape, and below their glass transition temperature are rigid and can retain their original shapes or take on compressed shapes. In other words, protective packaging made of shape memory foams can take a compressed shape that is desirable for transport and storage, and can take other shapes which are required for protective packaging applications. The following references disclose examples of shape memory foams: U.S. Patent Nos. 5,049,591, 5,093,384, 5,418,261, and Tey et al., Smart Materials and Structures, 2001, 10, 321-325. The present invention meets this objective with the protective packaging that has for at least one of its components a shape memory foam, which has shape memory characteristics.

Therefore, one aspect of the present invention is to provide the protective packaging that has for at least one of its components a polymeric foam that has shape memory characteristics. The protective packaging that can be easily compressed (deformed) into a shape that is convenient for storage and

transportation, and that can substantially regain its original shape or take on other shapes needed in the protective packaging applications.

In certain embodiments, the shape memory foam can be a thermoset or thermoplastic polyurethane foam, having a glass transition temperature, T_g, which can be above about room temperature, which is commonly referenced at about 21°C, in certain embodiments, above about 35°C, and in other embodiments above 50°C. The foam is rigid below the T_g and elastic above the T_g. The foam has shape memory characteristics such that when it is compressed (deformed) at a temperature above the T_g and cooled in that compressed (deformed) shape to a temperature that is below the T_g, the foam remains in that compressed shape without any aid from an outside force, and when the temperature is then raised above the T_g the foam returns substantially to its original shape and size. In other words, the foam possesses hibernated elastic memory of its original shape in the rigid state and is called "shape memory foam."

For the purpose of this invention, the T_g refers to a temperature at which the polymer undergoes a transition from elastic to rigid, as determined by differential scanning calorimetry or dynamic mechanical analysis. In certain embodiments, the shape memory foams used in this invention have a single T_g. In certain embodiments, if the shape memory foam has a broad glass transition or multiple glass transitions, the lowest temperature at which the glass transition occurs can be above about room temperature. In other embodiments, the glass transition temperature can be below about room temperature.

The protective packaging of the present invention is heated above the T_g of shape memory foam until it becomes elastic, at which point it is compressed (deformed) from its original shape (which can be of any size and shape) into a shape that occupies less volume, and it is cooled in that compressed shape to a temperature below the T_g until rigid. The protective packaging remains in that compressed shape without any aid of an outside force as long as it is kept at a temperature below the T_g. The protective packaging in a compressed shape can be packed, stored, and transported.

Prior to packaging applications, the protective packaging of the present invention is heated above the T_g until it regains its original shape. At this point, when the protective packaging has substantially regained its original shape and while still elastic (its temperature above the T_g), it can be placed in between an article that is being protected and packaged and the walls of a box (or a container). Since the shape memory foam is elastic while above the T_g, the protective packaging will conform around at least a portion of an article and once the shape memory foam cools below its T_g, it rigidizes and provides a custom-fit protective cushion.

While elastic, the protective packaging of the present invention can be wrapped around one or more articles, once it is cooled below its T_g, it rigidizes around the article(s). At this point, the wrapped article(s) can be placed into a container, however, that may not always be necessary.

On the other hand, prior to application in packaging, the protective packaging of the present invention in a compressed shape is heated above the T_g until it becomes elastic and regains its original shape. At this point, the protective packaging is cooled in its original shape to a temperature below the T_g to rigidize. The original shape of the protective packaging can be designed to provide a custom-fit to a specific article (or several articles), which provides a custom-fit protective packaging. In certain embodiments, the article in the protective packaging is placed in a box (or a container).

Alternatively, the shape needed to custom-fit one or more articles can be achieved by pressing the protective packaging of the present invention in its original shape, into a die at any temperature, but in certain embodiments at a temperature above the T_g, followed by cooling below the T_g at which point the protective packaging will remain in a deformed (compressed) shape that is a negative of the topology of a die.

SMFs are polymeric foams that have shape memory characteristics. An example of shape memory characteristics is illustrated in FIG. 1. The illustration shows a SMF that is a block in its original shape (shape I). SMFs are

rigid below the glass transition temperature (T_g) and elastic above the T_g. For most packaging applications, the T_g of a SMF needs to be above room temperature, which is commonly referenced at about 21°C. When heated to a temperature above the T_g, the flexibility of a SMF allows it to be compressed (deformed) from its original shape (shape I) into a compressed shape (shape II). When the temperature of a SMF, which is in its compressed shape (shape II), is brought to a temperature below the T_g, it becomes rigid and no external forces are required to keep it in a compressed shape, i.e. the foam is "frozen" in that shape. Subsequently, when the temperature of a SMF is brought to a temperature above the T_g, it becomes flexible again and it expands to restore its original size and shape of a block (shape I). At this point, when cooled to a temperature below the T_g, the foam rigidizes in its original shape (shape I). The cycle illustrated in FIG. 1 can be repeated.

In certain embodiments, SMFs used in the protective packaging of the present invention should have a T_g greater than about 21°C so that the foam is rigid at room temperature. In other embodiments, SMFs can have a T_g of at least about 35°C, and in other embodiments of at least about 50°C. In certain embodiments, SMFs used in the protective packaging of the present invention could have a T_g lower than about 21°C.

In certain embodiments, SMFs used in the protective packaging of the present invention have an open cell structure. The open cell structure can be achieved in various ways, for example by appropriate selection of cell openers and/or surfactants, or by standard reticulation (elimination of cell windows) methods applied on foams at flexible (elastic) state above the T_g. The open cell structure of the foam allows it to be compressed to less than its original volume. In certain embodiments, SMFs are compressible, without significant damage to its structure and its properties, to less than about 20% of its original volume, in other embodiments, less than about 10%, and in yet other embodiments, about 5%. The foam can substantially recover its original volume and shape when its temperature is raised above the T_g.

In certain embodiments, SMFs used in the protective packaging of the present invention can have good heat resistance so that they can go through multiple cycles of shape changes without significant damage to its structure and properties. In certain embodiments, SMFs are substantially undamaged at a temperature of about 120°C. In certain embodiments, the SMFs used in the protective packaging of the present invention have good resistance to water. In certain embodiments, the SMFs used in the protective packaging of the present invention can be resistant to moderate levels of ionizing (alpha, beta, gamma, x-ray) and non-ionizing (ELF, VLF, RF, Microwave) radiation.

As non-limiting examples of composition and for preparation of polyurethane SMF, an isocyanate component and a polyol component can be mixed in the ratios presented in Tables 1-2, corresponding to Examples 1-6 and 7-12. Surfactants, cell openers, blowing agents, and catalysts were also added as indicated in Examples 1-12. The mixture is poured into a mold and the reaction occurs at room temperature. Post curing of resulting foam at higher temperatures followed, but is not always necessary. After curing, the foams were crushed at a temperature above the T_g to produce an open cell structure. The foam is then cut into a desired shape as required for a protective packaging application.

Some non-limiting examples of suitable aromatic polyester polyols are ortophthalic diethylene glycol polyester polyols with functionality of 2, such as Stepanol PS-2002 (equivalent weight of 288) and Stepanol PS-1752 (equivalent weight 316) sold by Stepan Company. Other non-limiting types of aromatic based polyester polyols can also be used for preparation of SMFs, including terephthalate based polyols manufactured utilizing dimethyl terephthalate (such as Terate polyols, KOSA) or polyethylene terephthalate (such as Terol polyols, OXIDE).

In addition to the aromatic polyester polyols, polycarbonate polyols can also be used to prepare the foams of SMFs, such as poly(cycloaliphatic carbonate) polyol PC 1667 (Stahl USA). These polyols are also characterized with great rigidity. Advantageously, aromatic polyester polyols and polycarbonate

polyols produce a foam having good heat resistance, good moisture (water) resistance, and good radiation resistance.

A combination of aromatic polyester polyols and polycarbonate-based polyols, as well as mixtures of these polyols with other polyols such as polyether-based polyols, and mixtures of these polyols with chain extenders (e.g., short chain aromatic or aliphatic diols or diamines) can be used to prepare SMFs. In certain embodiments, the average functionality of polyol mixtures is between about 2 and 4, in other embodiments, between about 2 and 3, and in yet other embodiments, between about 2 and 2.3.

The polyol is reacted with an isocyanate in the preparation of polyurethane SMF. In certain embodiments, the isocyanate is an aromatic isocyanate having a functionality between 2 and 3, in other embodiments, between 2 and 2.7, and in yet other embodiments, between 2 and 2.4. Two examples of suitable aromatic isocyanates include Lupranate M10 (polymeric diphenylmethane diisocyanate having a functionality of 2.2 and an equivalent weight of 132) sold by BASF, and Isonate 50 O,P" (2,4-/4,4'-diphenylmethane diisocyanate having a functionality of 2.0 and an equivalent weight of 125) sold by Dow. Some examples of chain extenders are ethylene glycol, 1,4-butanediol, hydroquinone (2-hydroxyethyl)ether, and aromatic secondary diamines such as Unilink 4200 (UOP).

In addition to the polyol and the isocyanate, the polyurethane SMF can also include other components typically used in foams, such as blowing agents, cell openers, catalysts and surfactants. Some examples of suitable blowing agents include water (reaction with isocyanate gives CO_2), low-boiling organic compounds (e.g., hydrocarbons and halogenated hydrocarbons such as methylene chloride, dichlorofluoroethane, pentane, hexane, and various refrigerants), acetone, "azo" compounds which generate nitrogen, and the like. An example of a suitable cell opener is Ortegol 501 (Goldschmidt). Some examples of suitable catalysts include stannus octoate, tertiary amine compounds such as triethylene diamine, bis(dimethylaminoethyl)ether, and organometallic compounds. Some examples of suitable surfactants include silicone surfactants and alkali metal salts of fatty acids.

EXAMPLES 1-6

Table 1 discloses polyurethane foam formulations and their properties in Examples 1-6 that can be used in the protective packaging of the present invention. The component values are in grams.

Component	**1**	**2**	**3**	**4**	**5**	**6**
Polyol A	-	50	50	50	50	50
Polyol B	50	-	-	-	-	-
Polyol C	-	-	-	-	-	-
Surfactant	-	0.17	0.17	0.25	0.25	0.25
Cell Opener	-	0.5	0.15	0.11	0.10	0.10
Water	2.0	0.8	0.8	0.4	0.1	-
Blowing Agent	-	14.0	14.0	14.0	14.0	14.0
Catalyst A	0.3	0.15	0.15	0.15	0.10	0.05
Catalyst B	-	0.05	0.06	0.10	0.10	0.10
Isocyanate A	50.2	34.7	34.7	28.9	24.4	23.0
Isocyanate B	-	-	-	-	-	-
Properties						
Isocyanate Index	100	100	100	100	100	100
Density (Pcf)	2.7	1.4	1.6	1.5	1.8	1.7
T_g (DSC)	-	42°C	-	41°C	40°C	41°C
T_g (DMA)	-	54°C	-	57°C	54°C	49°C

Table 1

Polyol A: Stepanpol PS-2002, Stepan [ortophtalate-diethylene glycol polyester polyol (eq. wt. 288; functionality 2)]

Polyol B: Stepanpol PS-1752, Stepan [ortophtalate-diethylene glycol polyester polyol (eq. wt. 316; functionality 2)]

Polyol C: Terate 203, KOSA [terephthalate based polyol manufactured utilizing dimethyl terephthalate (eq.wt. 180; functionality 2.3)]

Surfactant: Dabco DC 193, Air Products (non-hydrolyzable silicone surfactant)

Cell Opener: Ortegol 501, Goldschmidt

Blowing Agent: Genetron 141-b, Allied Signal [dichlorofluoroethane]

Catalyst A: Dabco 33LV, Air products [33% triethylene diamine in dipropylene glycol]

Catalyst B: Niax A-1, Urethane Additives [70% bis(dimethylaminoethyl)ether and 30% dipropylene glycol]

Isocyanate A: Lupranate M10, BASF [polymeric diphenylmethane diisocyanate (eq. wt.=132; functionality 2.2)]

Isocyanate B: Isonate 50 O,P", Dow [2,4-/4,4'-diphenylmethane diisocyanate (eq. wt.=125; functionality 2.0)]

DSC: differential scanning calorimetry. DMA: dynamic mechanical analysis.

EXAMPLES 7-12

Table 2 discloses foam formulations and their properties in Examples 7-12 that can be used in the protective packaging of the present invention. The component values are in grams. The specific components are the same as disclosed in Examples 1-6.

Component	**7**	**8**	**9**	**10**	**11**	**12**
Polyol A	-	-	-	-	-	-
Polyol B	-	-	-	-	-	-
Polyol C	50	50	50	50	50	50
Surfactant	0.2	0.25	0.25	0.25	0.25	0.25
Cell Opener	0.5	0.5	0.5	0.2	0.1	0.2
Water	1.0	0.8	0.1	0.05	-	0.05
Blowing Agent	12	13	12	14	14	14
Catalyst A	0.4	0.25	0.2	0.05	0.05	0.05
Catalyst B	0.1	0.01	0.01	0.1	0.1	0.1
Isocyanate A	51.3	48.4	38.1	37.4	36.7	-
Isocyanate B	-	-	-	-	-	35.4

Properties						
Isocyanate Index	100	100	100	100	100	100
Density (Pcf)	2.0	1.8	1.9	1.7	1.8	2.0
T_g (DSC)	-	73°C	-	-	-	69°C
T_g (DMA)	-	-	-	-	-	-

Table 2

Besides the foams described in Examples 1-12, any thermoset or thermoplastic foam exhibiting the shape memory characteristics, and the blends thereof, can be used in protective packaging of the present invention, that include but are not limited to foams based on polyurethane chemistry, polyurea chemistry, or any other chemistries or methods that produce foams which exhibit shape memory characteristics.

In addition, blends of SMFs with other thermoplastic and thermoset polymers can be used in the protective packaging of the present invention, as well as composites of SMFs with other polymeric materials, organic or inorganic fibers, glass fibers, carbon black, substrates made of natural fibers, or woven and non-woven substrates. Also, in the protective packaging of the present invention, additives can be added to SMF to change its mechanical, thermal, and surface properties, resistance to biological agents, resistance to ionizing and non-ionizing radiation, as well as its affinity to water.

In the protective packaging of the present invention, SMFs can be wrapped, laminated, coated, or enclosed with polymeric sheets or thin films, which can be thermoplastic or thermosetting, which may not have shape-memory characteristics, but can have shape-memory characteristics. SMFs used in the protective packaging of the present invention can also be wrapped, laminated, or enclosed with sheets or thin film made of natural fibers. SMFs used in the protective packaging of the present invention can be laminated, coated, wrapped or enclosed with sheets or thin films at any point before application in protective packaging. In addition, articles to be packaged can be wrapped, laminated, or enclosed with sheets or thin films, made of thermoplastic or thermosetting polymers, woven or non-woven materials, or natural fibers.

Heating of the protective packaging of the present invention can be achieved by several methods that include, but are not limited to, convection ovens of any type, microwave ovens of any type, free or forced convective heating, conductive heating, radiation, light, electric field, magnetic field, ultrasound, or chemical reaction. Cooling of the protective packaging of the present invention can be achieved by several methods that include, but are not limited to: free convection, forced convection, refrigeration, conductive cooling, cooling baths, liquid or gas nitrogen, or any other cooling gas or liquid. The heating and/or cooling source can be imbedded to be a part of the protective packaging of the present invention.

FIG. 1 shows that the SMF used in the protective packaging of the present invention in shape I can be compressed into shape II at a temperature above its T_g, and once cooled in that compressed shape to a temperature below its T_g, it rigidizes and remains in shape II without any aid from an outside force. In compressed shape II, at temperatures below its T_g, the protective packaging made of SMFs can be packaged, transported, and stored.

FIG. 2 shows an example of a polyurethane SMF, prepared according to Example 2, at a temperature below its T_g, in its original block shape and compressed sheet shape. The SMF can be produced in a variety of shapes and sizes and compressed (deformed) to a variety of shapes and sizes.

As depicted in FIG. 3, prior to protective packaging applications, a compressed sheet of the protective packaging made of SMFs is heated to a temperature above the T_g until it substantially regains its original shape (shape I).

In its original shape, at a temperature above its T_g, the protective packaging made of SMFs can be used in the packaging applications as described in FIGS. 4 and 5. Two or more pieces of the protective packaging, which are above the T_g in their original shape, can be placed between an article and the walls of a container, after which point a container is closed. Since the SMFs are elastic while above the T_g the protective packaging will conform to the shape of an article and substantially fill the voids in a closed container. Once the SMF cools below the T_g,

the foam rigidizes and provides a custom-fit protective packaging for the article being protected.

FIGS. 6, 7, and 8 show how SMFs used in the protective packaging of the present invention can be pre-molded or cut into original shapes that custom-fit articles that are being shipped and protected, and snugly fit in a container (or a box). The SMFs can be compressed at a temperature above the T_g, and when cooled in compressed shapes to a temperature below their T_g they remain in those shapes without the need of an outside force. In compressed shapes, at temperatures below its T_g, the packaging made of SMFs can be packaged, transported, and stored. Prior to protective packaging application, a custom-made shape of the SMF is regained after heating to a temperature above their T_g. The SMF can be cooled below the T_g in custom-made original shapes to rigidize before application in protective packaging. In certain embodiments, articles encased in the protective packaging made of shape memory foams are placed into a container or a box.

FIG. 6 describes an application in which the protective packaging of the present invention made of shape memory foam is deployed from a compressed shape (II) to its original custom-made shape (I) at a temperature above the T_g. Once cooled below the T_g in its original custom-made shape, the protective packaging made of shape memory foams can be used to custom-fit an article that is being packaged. In certain embodiments, the protective packaging is designed to snugly fit into a box or a container. However, in certain applications it may not be necessary to place an article in the protective packaging in a box or a container. The protective packaging can be designed to custom-fit one or more articles that can have same or different topologies.

FIG. 7 describes an application in which the protective packaging of the present invention made of shape memory foam is deployed from a compressed shape to its original custom-made shape at a temperature above the T_g. Once cooled below the T_g in its original custom-made shape(s), several pieces of the protective packaging can be used to custom-fit one or more articles, that can have same or different topologies. In certain embodiments, an article in the protective packaging

can be placed in a box or a container and the protective packaging can be designed to snugly fit into a box or a container.

FIG. 8 describes an application in which the protective packaging of the present invention made of shape memory foam is deployed from a compressed shape to its original custom-made shape at a temperature above the T_g. Once cooled below the T_g in its original custom-made shape(s), one or more pieces of the protective packaging can be used to custom-fit one or more articles, and to snugly fit into a box or a container, without having to completely fill the void in a container or a box.

FIG. 9 illustrates how several articles can be packaged in a container by using several pieces of the protective packaging of the present invention. In certain embodiments, the shape of the protective packaging can be specially designed for the purpose of stacking and to custom-fit articles. However, the packaging as described in FIGS. 4 and 5 might be adequate for certain types of packaging.

FIG. 10 depicts the protective packaging of the present invention used to wrap or encase an object. FIG. 10 illustrates using a sheet of the protective packaging made of SMFs at a temperature above the T_g to encase a cylinder. Once cooled below the T_g, the protective packaging remains around a cylinder. Similarly, articles of different shapes and sizes can be wrapped or encased with one or more pieces of the protective packaging. Furthermore, articles of different shapes and sizes can be partially or fully wrapped or covered with the protective packaging of the present invention. Articles encased in the protective packaging do not have to be placed into a container or a box, but can be placed into a container or a box.

FIG. 11 describes how the protective packaging of the present invention made of shape memory foam(s) can be deformed in a die (D) at any temperature, but in some embodiments at a temperature above the T_g, and then cooled in a die to a temperature below the T_g to produce a shape that is a negative

of the topology of a die. By using this method a shape can be produced to custom-fit and protective one or more articles (A) as was described in FIGS. 6-9.

SMFs can also be used as loose-fill packing particles. SMF particles used in this application can vary in size and shape. The particles can be transported and stored in compressed shapes. Prior to applications in packaging, the particles can substantially regain its original shape and volume by heating above the T_g, at which point they can be applied as loose-fill packing material. These loose-fill packing materials can be made by cutting larger pieces of SMF into smaller particles at temperatures below or above the T_g. In certain embodiments, when the loose-fill particles are being cut out of large pieces of SMF, these large pieces of SMF are in compressed (compacted) shape at a temperature below the T_g.

For added levels of protection, articles to be packaged can be wrapped, encased, or laminated with sheets or thin films composed of polymeric materials, woven and non-woven materials, and natural fiber materials, before they are packaged with the protective packaging of the present invention. In addition, in the protective packaging of the present invention, SMF, or the blends there of, can be laminated, coated, wrapped, or encased in other materials, such as polymeric materials, woven and non-woven materials, and natural fiber materials. In addition, SMFs can be laminated, wrapped, encased, or coated with flexible, semi-flexible, or viscoelastic materials that are made of synthetic polymers or natural materials. SMFs can be laminated, coated, wrapped, or encased during or right after manufacture of SMFs, before, during, or after transport, or immediately before application in protective packaging applications.

Protective packaging comprised of shape memory polymeric foam and methods of using shape memory polymeric foam in protective packaging applications as disclosed in this patent can be applied to, but are not limited to, packaging of electronics, such as computers, monitors, printers, cameras, electronic components, food items, glass items, furniture, and any other article that require protective packaging.

While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrate and describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention.